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STABLE PRESSURE TRANSDUCER

J. H. COLWELL
PRESSURE AND VACUUM SECTION
HEAT DIVISION, NBS
WASHINGTON, D.C. 20234

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INTRODUCTION

The development of a stable pressure transducer for use up to 10,000 psi has centered on the solid dielectric capacitance gauge. Capacitors made from a large number of different dielectric materials have the stability and sufficient pressure dependence to be used in a device having the desired pressure resolution. The principal obstacle in the development of a pressure gauge from these materials is the temperature dependence of the capacitor; for the precision required, the temperature of the device must be compensated to levels of the order of 1mK. Thermostating to this level of accuracy is not convenient even under the best laboratory conditions and the time required to reestablish thermal equilibrium after a pressure change would be inordinately long in many cases. Much effort has been expended, therefore, in an experimental survey of the temperature and pressure coefficients of capacitors from many likely dielectric materials but none has been found with a small enough temperature coefficient to significantly reduce the problem. A theoretical study has not indicated any materials of great promise (at least none that experimental data bears out). Although the search continues for materials with small temperature coefficients we are presently concentrating on other ways of compensating for the temperature dependence, such as using pressurized and unpressurized samples of the same dielectric material in opposite sides of the bridge circuit or using two different dielectric materials in the pressure cell in such a way that their temperature dependences cancel.

Since the types of capacitance measurements under consideration all require the same basic bridge circuitry we are proceeding with the development of an automatic capacitance bridge which is described in some detail. Progress has been made in the

evaporation of sample electrodes and in the masking of the samples to form the gaps between electrodes.

SAMPLE ELECTRODES

Nearly all the work on dielectric capacitance gauges has been plagued by poor adherence of the deposited electrodes on the dielectric samples. Although the cleanness of the sample surfaces was long thought to be the problem, scrupulous cleaning of the samples and long periods of outgassing in the evaporator prior to coating still resulted in electrodes that could be easily scraped off with a fingernail and could be pulled off completely with Scotch Tape - a common test of coating adherence. After experimenting with various coatings and techniques the problem has been largely overcome through the cleaning of the sample surfaces by ion bombardment with a glow discharge in air for about 10 minutes prior to coating. Many samples have been coated after ion bombardment by evaporating Al or Cr and by sputtering Au, all give adequate adhesion. Repeated attempts to pull off the coatings with Scotch Tape usually results in some fraying at the edge of the sample or at the edges of the masked gap but this is rather abusive treatment.

Several rings for masking the gap between the low electrode and the guard ring have been produced which result in gap widths of about 0.01 mm (0.0004"). These rings have been ground from hardened steel and should prove much less susceptable to damage than were the earlier mild steel rings that were in use.

There is still a problem with the masking rings shadowing small areas of the sample during evaporation of the electrodes even though two sources are used and the samples are swept back and forth across the evaporator. The evaporator has now been adapted so that samples can be rotated above the source so that it should be possible to achieve a more unfiorm coating.

AUTOMATIC CAPACITANCE BRIDGE

The capacitance bridge as presently conceived is a limited range device designed specifically for use with the dielectric capacitance pressure gauge. It will be capable of measuring the ratio of capacitors which differ by less than 10% and which also have reasonably small loss tangents. After an initial phase adjustment, using a phase compensated resistor, the bridge is intended to be completely automatic.

The design of the bridge proper, shown in Fig. 1, is in principle the same as that presently being used as a research tool in our laboratory. The bridge transformer forms the 1:1 ratio arm of the bridge and supplies the voltage for the ratio transformer used in balancing the bridge. The output voltage of the ratio transformer is injected into one of the ratio arms of the bridge through the two stage transformer. The power for this injected voltage comes from an operational amplifier so that there is no loading of the ratio transformer and the bridge impedance is kept small. It is the turns ratio on the two stage transformer and the voltage supplied to the ratio transformer that limits the range of capacitor ratios that can be measured. A switch on the primary of the two stage transformer allows the selection of a total range of either 1 or 10%. The switch on the input to the ratio transformer allows this range of bridge ratios to be taken on either the positive or negative sides or centered about the ratio of 1. Any difference in loss between the measuring capacitor and the reference capacitor is compensated by injecting an in-phase, i.e. resistive component, signal into the detector arm of the bridge. The magnitude of this signal is controlled by multiplying the D.C. in-phase signal of the phase sensitive detector by an A.C. signal from the bridge transformer. The exact phase alignment of the bridge will be manually adjusted by balancing out the signal from a pure resistance.

Fig. 2 is a block diagram of the logic ciruitry as presently planned for the automation of the capacitance bridge. The design is limited to some extent by the incorporation of a 5 decade programmable ratio transformer (PRT). We require a 7 digit reading and would desire 8 digits, so it is necessary to limit the range of capacitance ratios that the instrument can cover. In the 1% range the first two significant digits are preset by the range control, in the 10% range only the first significant digit is preset. The next five significant digits are determined by the ratio transformer and two additional digits are obtained by the digital conversion of the analog voltage resulting from any remaining bridge imbalance.

In operation the imbalance current from the capacitance bridge is amplified by an FET preamplifier and by three programmable gain amplifier sections. These are followed by two lock-in amplifiers, one phased to detect the resistive loss component of the bridge and the other phased at 90° to detect the capacitive imbalance. The rectified loss component is further filtered and used to control the automatic loss feedback network in the bridge. This signal can be monitored by a front panel meter.

The rectified capacitance imbalance signal is fed to the gain control module and to two voltage-to-frequency converters (VFC). The signal is inverted before one of the VFC's, so that one VFC delivers a pulse rate proportional to positive signals and the other to negative signals.

The output of the two VFC's are fed into a bank of 14 up-down counters by way of a multiplex unit that switches in and out various counters. After each period of counting the contents of the counters is dumped into latches which hold that count whil the next is in progress. The signals from the latches are routed through buffers to the BCD output for external processing and are routed to the seven-segment decoders which generate a 10 digit LED display. The signal from latches 4, 5, 6, 7, and 8 are routed through drivers to the programmable ratio transformer and provide the update bridge setting. Only decades 9 through 13 are zeroed before each count so that the new count is added to or substracted from the existing transformer setting.

The clock steps down the bridge frequency to approximately 10 second and 1 second intervals which are used as counting times. The clock is used to turn the counters on and off, and while the counters are off enables the gain control and range control, transfers information from the decade counters to the latches, zeros counters 9 through 13 and turns on the counters for the next interval.

The gain control looks at the output of the bridge and sets the amplifier gain decades to keep the input to the VFC's less than 10 volts but greater than 1/2 volt. It is operative only when the counters are off. When the amplifier gain changes the counting gain or count time must change to keep the overall gain constant. The counter gain is changed by the multiplexers switching between the last five decade counters. On the highest amplifier gain the clock is set for 10 second counts; on all other gains it is set for 1 second counts.

The range control switches between the following deviation capabilities of the bridge:

0 to 1%	0 to 10%
± 1/2%	± 5%
-1 to 0%	-10 to 0%

The switching is done automatically seeking the highest sensitivity, but can be set manually. Range control switching takes place only when the counter is off and only when the programmable ratio transformer is asked to go beyond its limit (as detected by a carry or borrow signal from counter 4'). Counters 1, 2, 3, 4, 4' are reset each time a range control switching occurs.

Decade counters 9 and 10 do not control the bridge. They are zeroed before each count and provide the two analog decades of bridge sensitivity beyond the ratio transformer setting.

The fourth decade is split, 4 going to the readout and 4' controlling the PRT. This was necessary to permit the use of the bridge ranges ± 1/2% and ± 5%. On these ranges, when the bridge ratio (and readout) is exactly 1.000, the PRT must be set to 50000, the 5 appearing in the fourth readout decade.

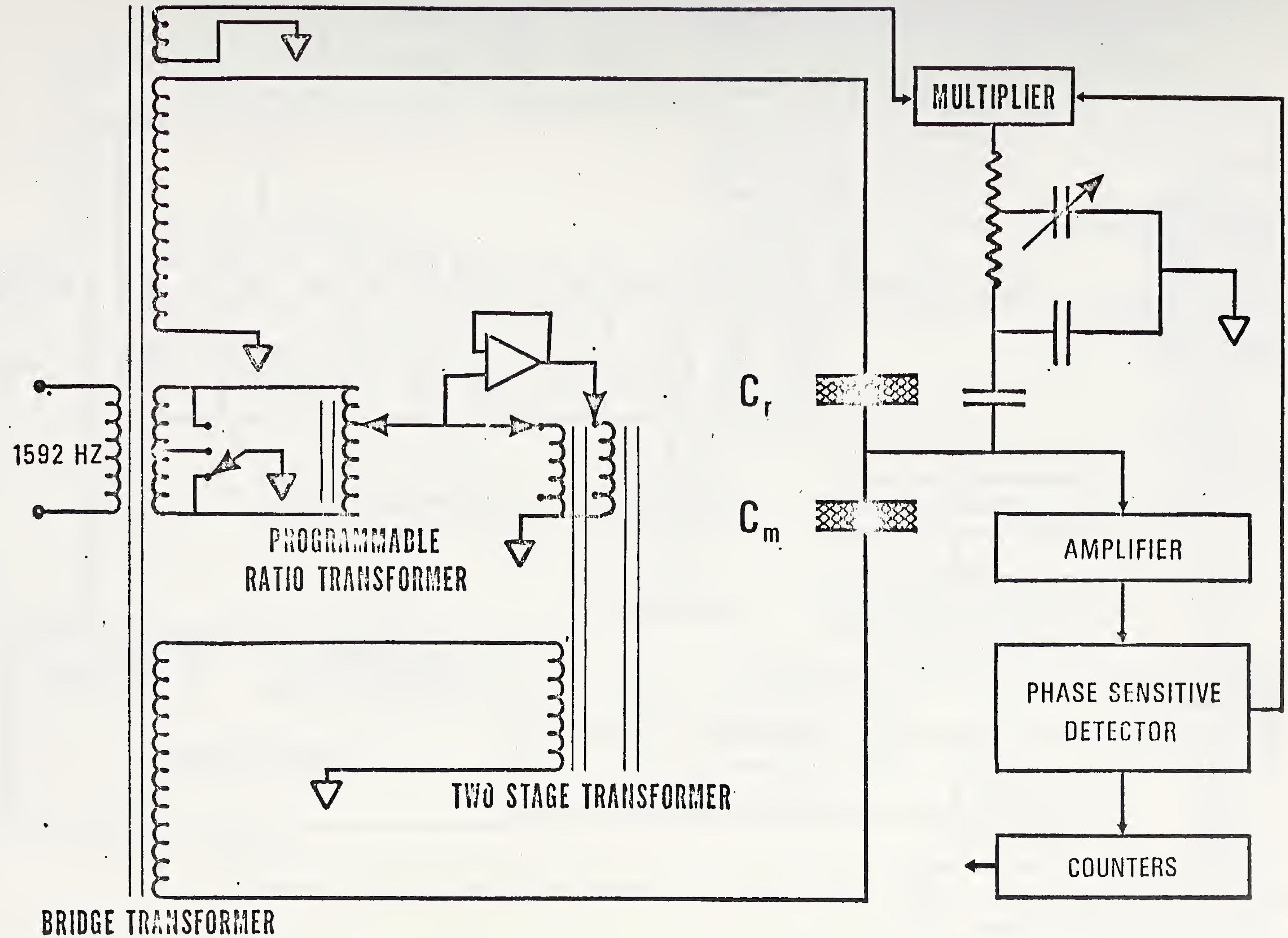
The precision desired from this bridge is pushing the limits of programmable ratio transformer. The stated accuracy of the instrument indicates that the two decades of analog data beyond that of the transformer may not be meaningful. The ratio transformer is being calibrated to establish its overall accuracy. It may require that the capacitance bridge be operated at the optimal frequency of the ratio transformer (400 Hz) rather than at 1592 Hz ($\omega = 10^4$) which we have been using in this laboratory.

FUTURE

Although we have not decided on the exact type of capacitance gauge which will be used we will proceed with working models of pressure cells so as to begin evaluation of not only the dielectric materials but component parts such as electrical contacts, electrical feedthroughs, and sample electrodes. There are numerous design criteria about which we have little information. Experience with our research cell, where minute dirt particles shorted the gap between the low electrode and the guard ring, show that the gauge should be isolated from the pressure fluid of the measuring system. We have no information of the effect of nonhydrostatic stress on the dielectric constant of samples to determine how critical the mounting of the sample may be. Tests are presently underway to determine how rapidly thermal equilibrium can be achieved in pressure cells. This information is necessary as design and performance criteria for any capacitance gauge in which the temperature dependence has to be compensated in some way.

We have started experimenting with smaller dielectric samples, 1/2" diameter instead of the 1" samples that we have been using. This miniaturization should have several advantages; aside from making the units more compact it should make the pressure cells much cheaper and opens the possibility of using the capacitance gauge to much higher pressures. Also from a research point of view, it allows measurements on dielectric materials which are not readily available in 1" discs.

CAPACITANCE BRIDGE



AUTOMATIC CAPACITANCE COMPARATOR